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WHAT SYNTAX DOES NOT KNOW:
Movement triggers beyond integration

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Abstract
Space syntax is generally geared towards identifying syntactic features in spatial layouts and predicting human usage patterns from configurations. From a psychological perspective it appears unlikely that people directly perceive such configurational features upon newly entering an environment and other perceptual features might have more direct impact on behaviour. In this study we experimentally juxtapose features typically captured by syntactic measures with perceptual features generally under-represented in such analyses, like local visual attractiveness of path choices.

Research on indoor navigation (e.g. Haq & Zimring, 2003; Hölscher, Brösamle & Vrachliotis, 2012) suggests that human route choices are reliably predicted by syntactic measures such as integration, both for free exploration of complex corridor layouts and for targeted wayfinding and search tasks. This paper reports a Virtual Reality wayfinding experiment that tests the relative impact of syntactic properties and perceptual attractiveness.

For this purpose we developed an experimental indoor environment that represents a roughly L-shaped hospital building with two main corridors passing through the middle. Syntactically, these two corridors had the highest integration (HH) and connectivity values of all the corridors in the building. These corridors have a total of 22 intersections and form the syntactic integration core (Peponis, Zimring & Choi, 1990) of the building. Two versions of this layout were programmed in a CAD tool: in version A (the control or baseline condition) all corridors were of the same colour, width and wall texture. In version B (the experimental condition) a sequence of corridor segments was visually highlighted by a bright colour, different textures and an increased width between walls. This path was of equal metric length as the syntactic integration core but contained fewer, only 9, intersections. The visual features were selected so that they were salient and provided characteristics that are typically associated with important main corridors in a building. In the experimental condition B, this highlighted corridor sequence can be considered a "fake integration core". The main hypothesis for the study is that this fake integration core would be used more in the visually highlighted condition and thus take activity away from the syntactic core and reduce the predictive power of syntactic features.

Layout variation was implemented as a between-participants factor, i.e. each of the 42 participants experienced only one version of the building. They explored the layout for five minutes, and were then taken along prescribed routes through the building to learn the location of four landmarks. Navigation to these landmarks was tested as well as search time for two additional new locations.

Analysis of path choices reveals a complex pattern of environmental and individual influences on movement patterns, including the location of start points and landmarks as well as idiosyncratic preferences. While the syntactic integration core has a substantial level of usage, highlighting the fake integration core strongly increases local movement attracted by local perceptual features. Overall this psychological experiment suggests that syntactic analysis and perceptual properties of an environment need to be considered to appropriately capture human movement behaviour.

Keywords: *wayfinding, integration, integration core, perception, cognition.*

Theme: *Spatial Cognition and Behaviours*

1. Introduction

The juxtaposition of spatial syntactic factors and local perceptual features of the environment is related to Hillier's (1996) distinction of significance and signification. Significance refers to information or meaning that derives directly from the syntactic configuration of a number of objects, specifically by being arranged in one way rather than another (and frequently with reference to precedent configurations). Signification, by contrast, refers to assignments of meaning that are basically outside of their own domain (meaning is derived purely through learned associations). While that distinction is more generally geared towards separating truly spatial syntactic relations from arbitrary linguistic binding of meanings to words and sounds, it can be applied here as follows: Both the configurational structure of the environment and other features such as colour, material and ceiling height convey information about the likely role or usefulness of specific part of a building for specific purposes. With respect to circulation in a building, both promote inferences about what purpose a corridor might serve and to where it might connect. The key difference between syntactic and other features is that configurational properties do not represent an arbitrary assignment, they basically communicate their very essence directly: A corridor that is well-connected or is centrally located in the building, thus directly affords different behaviours than more remote corridors. The central or well-connected corridor allows for – ceteris paribus - more exploration options, and these are expressed directly in the spatial layout. By contrast, the expectation that main corridors are designed to be brighter, nicer, more elaborate etc. is a convention, a social expectation about likely design decisions of an architect. While it makes practical and social sense to highlight an important corridor with colour or other features, there is no inherent necessity to do so. In other words, the syntactic features of a corridor network like connectivity and integration are structural properties with respect to human movement, while colour, material or ceiling height are semiotic features, not unlike man-made signs.

Space Syntax has traditionally concentrated on structural properties, and the present study sets out to demonstrate how human navigation behaviour is determined both by structural and semiotic properties. I.e., how humans rely on both types of information to guide their wayfinding decisions.

Research on indoor navigation (e.g. Peponis et al, 1990; Haq & Zimring, 2003; Hölscher, Brösamle & Vrachliotis, 2012) suggests that human route choices are reliably predicted by syntactic measures such as integration, both for free exploration of complex corridor layouts and for targeted wayfinding and search tasks. Results by Haq & Zimring (2003) suggest that such predictions capture both local and global syntactic features of the environment and allow for a comparison between buildings based on measures such as intelligibility. Hölscher et al. (2012) were able to show that VGA step depth between origin and destination serves as a strong predictor for the difficulty of a navigation task. The same study suggests that navigation strategies as well as differences between first-time visitors and repeat visitors can be captured through route-based variants of VGA step depth, integration and connectivity measures.

These studies have been conducted in existing buildings rather than highly controlled, simulated environments. While space syntax provides a refined set of tools for capturing the relevant structural properties of such complex spaces, no comparable technique currently exists for capturing the rich perceptual and semantic variability of scenes, corridors or places in a public building, including the rich detail of textures, moveable and stationary objects as well as co-presence of people. Therefore we have opted for a Virtual Reality wayfinding experiment that would allow for equally controlling syntactic, perceptual semantic properties in a highly systematic fashion. Authors like Franz & Wiener (2008; Wiener et al., 2007) as well as Dalton (2003) have shown that abstracted, computer-generated stimuli are a viable tool for capturing behavioural tendencies similar to real spaces. Nonetheless the results of any Virtual Reality study will inevitably focus on the features explicitly included in the simulated environments and thus be blind to other potentially relevant features in real-world spaces. While the present Virtual Reality wayfinding experiment is geared towards directly testing the relative impact of syntactic properties and perceptual attractiveness, any generalization to real buildings would need to take the inherent artificiality of the test environment into account.

Hypothesis

The main hypothesis is that in the experimental condition the participants will get distracted away from the syntactic core by the fake core, while in the control condition the participants will spent a significant amount of time using the main (syntactical core) axis of the building. Over the time spent in the building, the attraction to the highlighted corridors should fade and the real syntactical core should be used again, as the participants in the experimental condition obtain better knowledge of the building and realize that the fake core has no meaning in a syntactical way. It may turn out that the visually highlighted corridor at that point might be used simply as a landmark.

2. Methods

The experiment is based on earlier Space Syntax navigation studies by Peponis et al. (1990) and Haq and Zimring (2003). Like these authors, we have employed the basic structure of a large hospital-like building with long homogenous and nearly indistinguishable corridors for the control condition. In the experimental condition one corridor that does not belong to the syntactic integration core was emphasized so that the participants should be attracted by it and chose it over the more subtle structural hints. We call this corridor the 'fake integration core' throughout this paper.

Participants

Almost all of the participants were students at the University of Freiburg, Germany. Altogether there were 42 Participants, 4 participants were unable to finish the Experiment and are excluded from the analysis. The mean of the age of the participants was 23.5 with a standard deviation of 2.5. For taking part in the experiment the participants received either 7.50€ or one hour of course credit points.

The experiment ran on a three screen layout with a resolution of 5760px x 1200px giving a horizontal field of view of 156° at approximately 60 Fps. The trajectory was recorded every frame. The camera was controlled with a gamepad having two degrees of freedom (moving forward/backward and turning left/right). The camera was locked in the horizontal plane.

Environment

In the control/baseline condition only one type of corridor was used. It was well lit with bright finishing on the wall and bright tiles on the floor (Figure 1, upper right). Except for the two starting rooms there where only corridors. The participants were told that it is neither possible nor necessary to open any doors in the building.

In the experimental condition nearly all corridors were textured with the same bare and dirty concrete (Figure 1, middle right). These corridors were badly lit and 2.2 meters in width, which appears rather narrow on the VR-setup as the two side screens only show walls on both sides. They were intended to be unattractive and therefore only the bright corridor should appear as a good choice regardless of its lower space syntax connectivity and integration values. Like in the control condition these corridors were textured with bright wallpaper and bright ceiling and floor textures. The width of the corridors was 3 meters and they were higher than the other corridors. We assumed that this would be more attractive than the concrete version.

In both versions of the building we included two starting rooms with neutral textures. One at the (hypothetical) entrance of the building, from which the guided tours started, and one near the junction of the two most integrated corridors in which all other tasks begun.

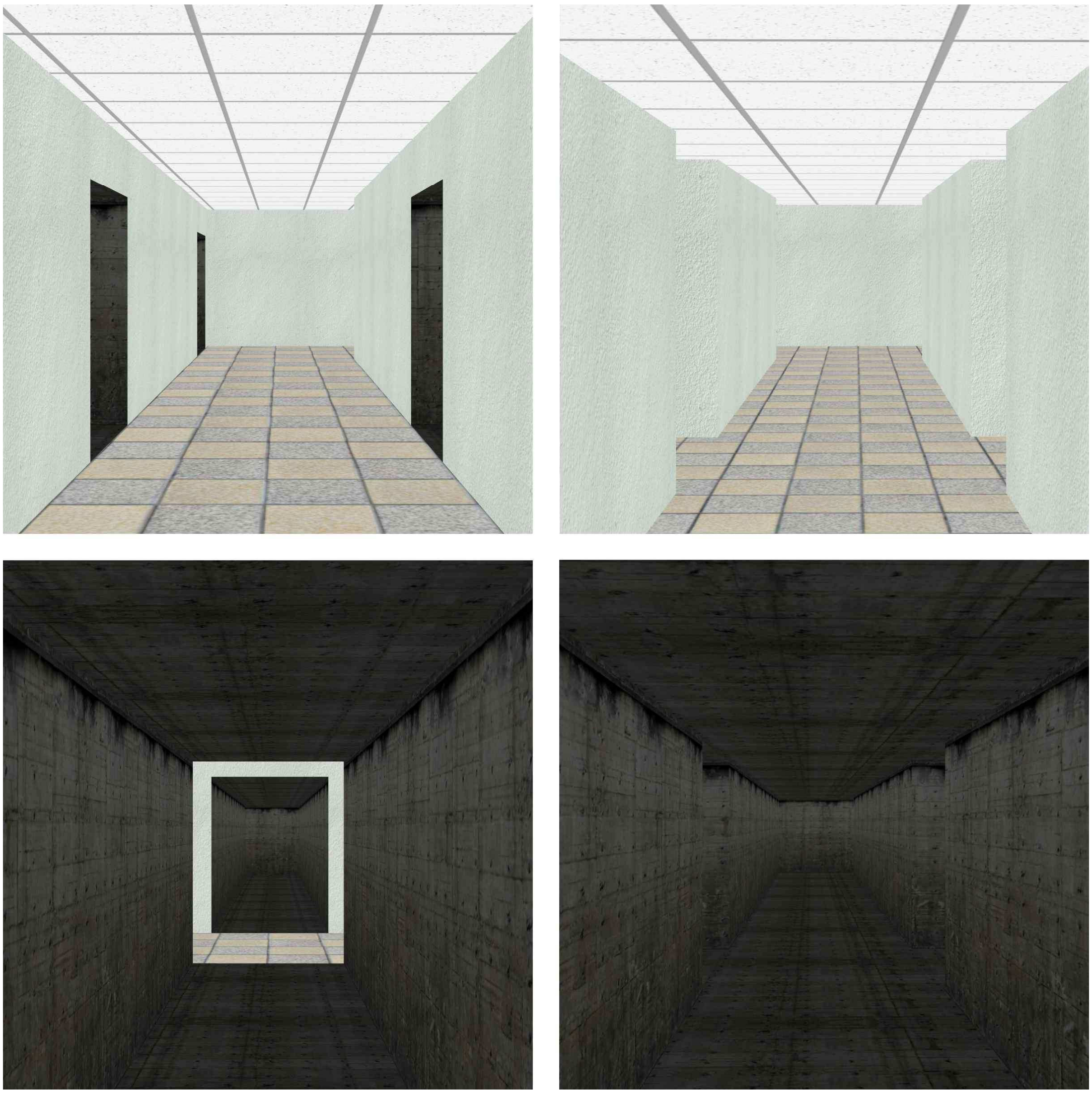


Figure 1: Scenes from the simulated building: The four possible types of junctions. The experimental condition featured the three junction types fake core to dark corridors (upper left), dark corridors to fake core (middle left) and dark corridor to dark corridor (middle right). The control condition had highlighted corridors (upper right) throughout. Bottom row: The initial view starting at A2

Tasks

As a training and pre-test for the real map, participants were placed in a 4 x 4 corridors grid world. Half of the training map was built with dark corridors; the other half of the map built from wide bright corridors. In this grid the participants were familiarized with the controls for three minutes. Afterwards the experiment continued with one of the hospital layouts.

Each task within the hospital had a maximum duration of five minutes. Overall there were eight tasks with different goals. From the beginning there were three landmarks placed in the building which could only be seen if the participant was close to them (they appeared within a 10 meter radius, the maximum distance that allowed the green cone landmark to be out of range from adjacent intersections, keeping it invisible while the participant stood on the integration core or fake integration core).

- 1: Exploration
  The goal was to familiarize oneself with the building, commencing from the starting room (see A1, A2 in Figure 2).
- 2 & 3: Guided tour (clockwise & anti-clockwise)
  The participants followed a red ball through the building. While following the ball they passed all three landmarks. This was a circular-route and the participants were guided along this route in both clockwise and anti-clockwise direction. The tour started from the B starting room (see Figure 2).
- 4, 5 & 6: Search for known landmarks
  The three landmarks should be searched one after another in a randomized order. The first task starts from (see Figure 2) starting room A. If the landmark isn't found within the time limit the participant was teleported to the landmark's position. Then the task goes on for the next landmark
- 7 & 8: Search for new landmarks
  The last set of tasks was finding two new landmarks which were added on predefined positions within the building. These tasks again started from (see Figure 2) starting room A

After the tasks in the virtual environment were finished, a questionnaire was handed to the participants evaluating some of the buildings qualities on a seven points scale from absolute disagreement to absolute agreement.

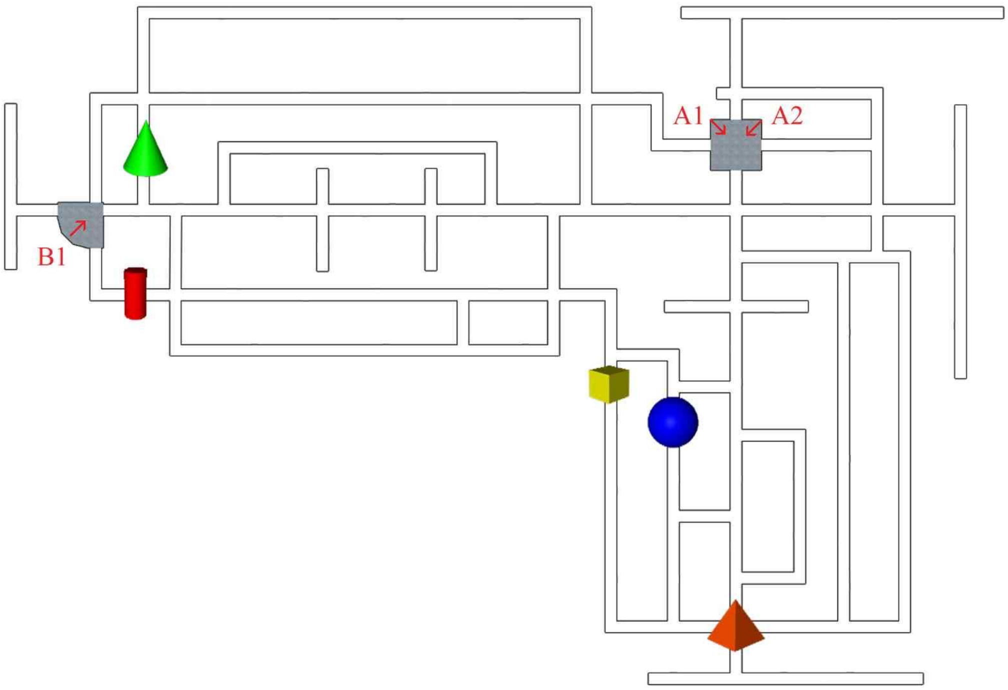


Figure 2: The three Landmarks known from the guided tour (green, orange, blue), and the two new landmarks (red, yellow). And the start rooms A and B with the start positions A1, A2 and B1.

Groups

We had three independent variables with two values each resulting in eight groups. The independent variables were the following:

1. Building layout
   Layout for distinction between control and experimental group.
2. Start point and orientation
   Resulting in a different view point at the start of a task, with inverted choices on the left and right side. Marked in Figure 2, with A1 and A2.
3. Guided tour direction
   To prevent a bias to either the syntactic core or the fake integration core the direction of the guided tour was switched.

As the orientation of the starting point and the direction of the guided tour were balanced and showed no effect on the behaviour, the analysis and results below is limited to the independent variable of building layout.

Analysis

For a basic movement analysis, a python script was written calculating the time and distance spent in certain areas. The areas were defined as the integration core, the fake integration core and the rest of the building (non-core areas). For the start room A (see Figure 1, bottom row) the first decision was computed separately. Along with this data we have the success rates in all search tasks and the time spent finding the landmarks.

In addition, we evaluated participants' behaviour at certain junctions. Similar junctions were grouped together into eight categories. Most of them were either located at the fake integration core, the integration core or both. Intersections not located at any of these cores were used to evaluate default behaviour tendencies (baselines). Comparing this default behaviour with the behaviour at the other types allows the determination of the influence of the syntactic and fake cores on movement decisions. For each type of junction we differentiate both the direction of entry and the direction of exiting. By comparing the arrival and leaving directions we were able to conclude whether the participants walked straight or turned in a certain type of location. Using this information the Intersection Turn-Probability Matrix (ITPM) is created, showing the average behaviour of the participants at different junctions.

3. Results

Training Map

The starting location in the training map was in one corner of the map facing a bright/dark decision (the starting point itself is excluded from every calculation). At the starting point 24 out of 29 (9 logs of the trainings map were invalid due to a smaller runtime) participants decided to take the well lit corridor over the darker one (χ^2 = 12.45 , df = 1, p<.005). The attraction of the light and wide corridors continued to an overall ratio of 1.42 times more time spent in the highlighted than in the dark part of the training map (one-sample t-test against random choice (factor of 1); t=3.64,df=28, p<.005, see Figure 3).

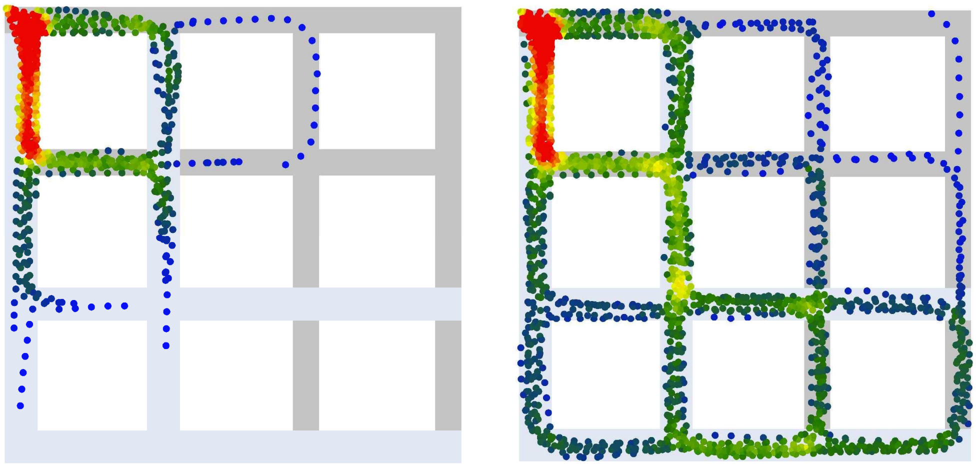


Figure 3: The training with the first seconds of choice (left) and the first half of the exploration time (right). The participant started in the upper left corner with the dark/light choice.

Basic trajectory analysis

At the beginning of the exploration phase participants in the experimental group had the choice between initially entering a part of the integration core and a part of the fake integration core. Similar to the training map, most of the people (16 out of 18) walked directly into the fake integration core whereas only 2 took the syntactical core of the building. By contrast, in the homogenous version of the building (control group) the minority of participants (6 out of 20) took the corridor that corresponds to the fake integration core in the other setting, and the remaining 14 participants initially walked down the syntactical core. As we will see in the ITMP section, this covers the observation that the participants are locally attracted by the fake integration core. Keeping to the exploration phase, we calculated the time each participant spent in the fake and the real integration core. Participants in the control group made frequent use of the integration core spending 98sec on average in this zone. The fake integration core was occupied with a duration of 61sec on average. The rest of the time is spent in corridors in neither group or in the starting room. In the experimental group, the Fake integration core was used 120 sec. on average, and only 55 sec. were spent on the real integration core. The difference between layout conditions is significant for the time spent on the integration core ($t=2.73$, $df=35.89$, $p<.01$) and for the time spent on the fake integration core ($t=-3.69$, $df=28.44$, $p<.005$) clearly showing the attraction of the visually highlighted corridor. A plot of the time (data points) spent in each corridor area can be seen in Figure 4.

During the exploration phase the syntactic integration core was entered 5.30 times on average per participant in the control group, but only 3.44 times in the experimental group ($t=2.13$, $df=35.85$, $p=.04$). The effect was not evident from the rate of entering onto the fake integration core. This together with the above results this indicates, that the experimental group did not enter the fake core more often, but stayed in there for a long time after entering once and held a reduced interest in the syntactic integration core of the building (table 1). Similar analyses for the search tasks remained inconclusive, as some people had perfectly learned the shortest routes from the guided tours while others got completely lost, yielding a large overall variance in movement behaviour.

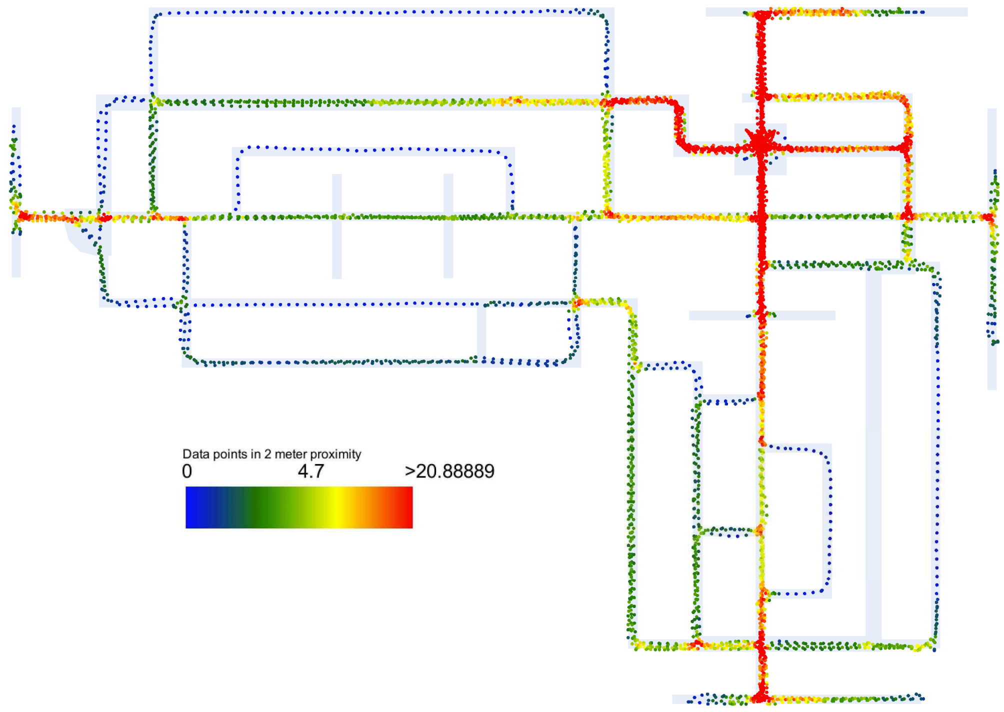
Table 1: Basic trajectory analysis: Exploration phase, search for known landmarks, new landmarks, and re-entries into corridor segments within each task.

Exploration (average values)	Time in Integrationcore	Time in FakeCore	Enters Integrationcore	Enters FakeCore
Control	98.35sec	61.91sec.	5.30	2.85
Experiment	55.35sec	120.45sec.	3.44	3.22
t-Test	.01	.005	.04	.39

Known landmarks (averages)	Time	Average Landmarks found	Time in Integration Core	Time in FakeCore	Reenters Integration core	Reenters FakeCore
Control	696.81sec.	1.35	243.91sec.	156.39sec.	2.20	1.10
Experiment	676.01sec.	1.44	221.71sec.	196.04sec.	1.56	0.44
t-Test	.68	.74	.41	.16	.31	.13

New landmarks (average values)	Mean Landmarks found	Reenters Integrationcore	Reenters FakeCore	Time in Integration Core	Time in FakeCore
Control	.40	2.75	1.60	127.98 sec.	114.78 sec.
Experiment	.39	1.83	1.39	111.02 sec.	124.30 sec.
t-Test		.92	.21	.42	.63

Re-Entries	Exploration	Search for Known landmarks	Search for unknown landmarks
Control	6.05	3.35	4.70
Experiment	3.78	2.00	3.44
t-Test	.07	.22	.32



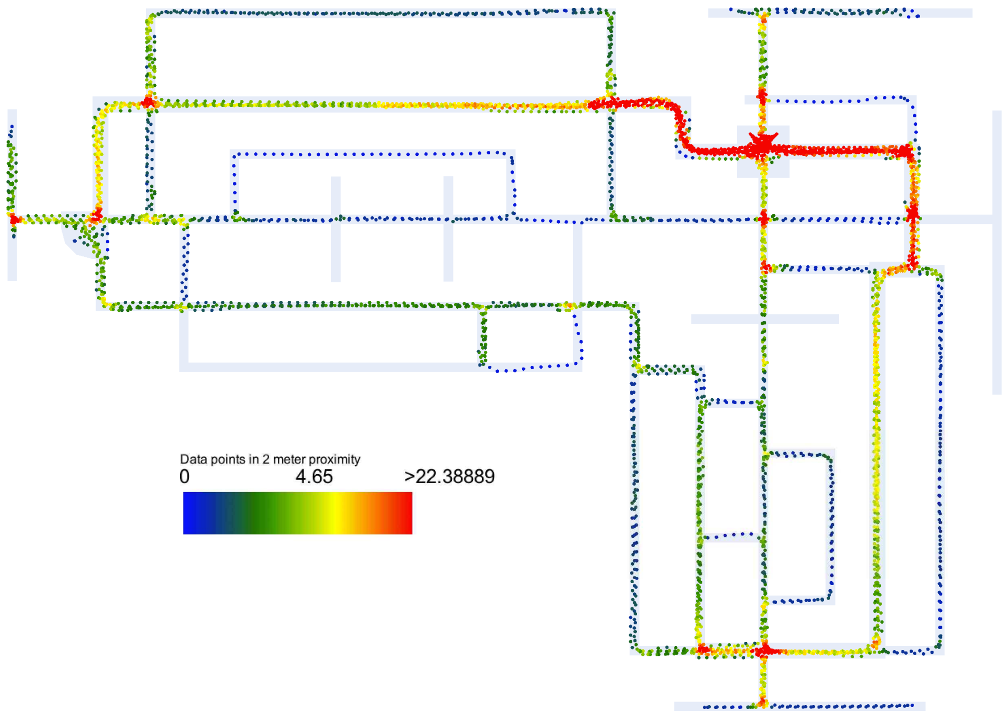


Figure 4: Movement of the control group (top) and experimental group (bottom) during the exploration phase. Data points where reduced to one per second.

Nonetheless we tried to determine what knowledge the participants had gathered about the building. We analysed the path segments re-entered, i.e., the number of times a corridor was (unnecessarily) entered more than once within a single task (please note that this is not to be confused with the entry rates in the first analysis above because now the first entry on each corridor segment is excluded). In the exploration task there was a statistical trend in the advantage of the experimental group which 3.78 corridor re-entries on average against the control group which re-entered 6.05 corridors ($t=1.8$, $df=36$, $p =.07$ two-tailed; significant in one-tailed t-test). Following this principle we analyzed the search tasks and observed weaker differences, yet in the same direction. In the search task for the known landmarks, there was an overall re-entry rate of 3.35 in the control and 2.0 in the experimental group ($t=1.26$, $df=36$, $p=.22$). In the unknown landmarks search the trend continued with 4.70 re-entries in the control group and 3.44 re-entries in the experimental group ($t=1$, $df=36$, $p = .32$). The experimental group also performed better in the search for the landmarks (both unknown and known), but not to a statistically reliable degree.

ITPM: Data Handling

As mentioned earlier we evaluated the decisions made at the different types of intersections in the building. In particular, this is performed to verify whether the presence of a fake integration core at an intersection influences the choice of the participants. In order to provide as much information as possible in a well-defined way all our results will be stored in the Intersection-Turn-Probability-Matrix (ITPM) for each type of intersection (see Figure 5). The ITPM takes into account both the direction of entry and exit.

For each category we looked for intersections with the same layout independent of the absolute location and rotation in the building. Of primary interest are the intersections with either the fake integration core or the real integration core. For example, all the junctions of the fake integration core and a normal way are in one group (type 0) independent of whether the fake integration core path goes from left to right or top to bottom or vice versa. All together there are 8 different types within the building. Furthermore, as mentioned above, not all of the intersection types are relevant for this study and we thus limited the report. For example, type 5 intersections are at the end of the real integration core and always lead to a dead-end, so independent of the experimental layout variation the participants don't have any choices relevant for the study. By contrast, intersection type 7 represents indistinctive standard intersections outside the cores and is used to estimate a default movement behaviour for both groups. The other types that are considered for the analysis have at least a fake integration or real integration core attached.

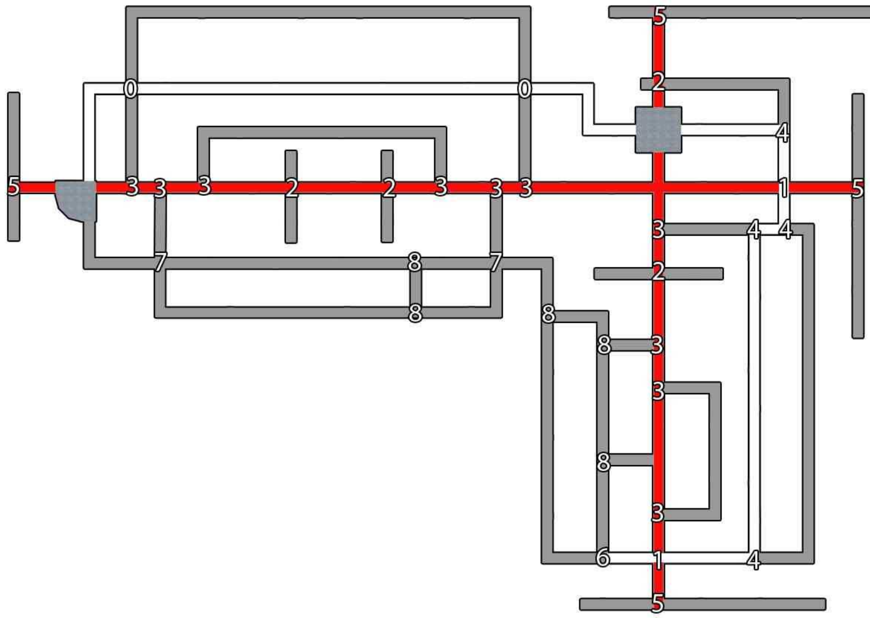


Figure 5: Different intersections, numbers indicate type of intersection.

Next we need to clarify which information is gathered at the junctions. For each junction type we determine how often a participant enters the junction and which decision is made, i.e., we record which way a participant arrives and leaves. Within this building there are only three types of corridors, the fake integration core, real integration core and the rest of the building with no special attributes. So for each intersection we record from the movement data the area in which the participant arrives and leaves. By comparing the areas we capture the decisions of the participants and we can evaluate if they were walking straight or took a turn at a junction.

ITPM Results

We start with an evaluation of the standard behaviour for the junctions. As said, these junctions are identical in both the control and experiment setting and have no specific features which make one path option distinguishable from another. Table 2 shows a tendency to walk straight at the junction rather than changing the direction. As expected this tendency is almost identical for both groups. Therefore we can use the average value as our approximation for the standard behaviour. We also evaluate if we can deduct a random behaviour from these values. We tested for a randomly distributed behaviour based on types of action (straight vs. turn) or possible directions (left, straight, right), i.e. t-tests against probability of .5 and .33 for going straight. The observed behaviour is significantly different from both of these random movement patterns ($t=3.1$; $df=39$, $p<.001$ and $t=10.17$; $df=39$, $p<.005$, respectively). The average rate of going straight in 57.3 % of cases is used as the default baseline for comparisons below.

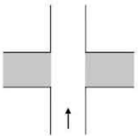
Table 2: average decision for the control and experiment group at type 7

	straight in %	turn in %
control	56.63	43.37
experiment	58.03	41.97
average	57.30	42.70

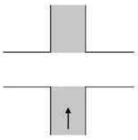
With the established standard behaviour we can create our ITPMs. They consist of different parts, resulting from slightly different evaluations. The first difference is the number of participants that were taken into account for each junction. This is necessary because not all participants passed each junction over each attached area so the number of participants (#participants) varies between the ITPMs. This can happen because we wanted the participants to freely explore the building with no external influence. So, not all of the participants entered every corridor of the building. The second part in the matrix is the actual probabilities for certain behaviour. E.g., for the ITPM type 0 (table 2, top section) the probability for a participant coming from the fake integration core and walk straight (and thus continuing on the fake core) is 50% in the control and 57.25% in the experiment condition. The last column is the statistical significance level (p-values) of the difference between the standard behavioural decisions (type 7) and the decisions observed at this type of intersection (one-sample t-test against default value). By contrast the last row of the ITPM indicates the result of a two-sample t-test comparing control and experiment group.

Table 3: ITPM analyses for intersection types 0, 1, and 4

type 0 – ITPM (fake core white, normal corridor grey)

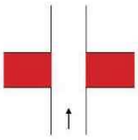


fake core	#participants	stay	turn	Comparison with default behaviour
control	18	50.00	50.00	p= .44
experiment	18	57.25	42.75	p= .97
t-test sig.	p= .54			

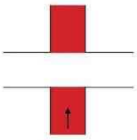


regular	#participants	stay	turn	Comparison with default behaviour
control	11	24.55	75.45	p= .02
experiment	13	21.15	78.85	p< .005
t-test sig.	p= .81			

type 1 – ITPM (fake core white, syntactic core red)

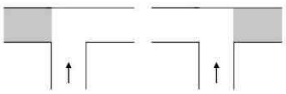


fake core	#participants	stay	turn	Comparison with default behaviour
control	13	29.49	70.51	p= .02
experiment	15	40.87	59.13	p= .16
t-test sig.	,47			

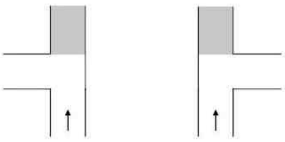


int. core	#participants	stay	turn	Comparison with default behaviour
control	19	59.81	40.19	p= .66
experiment	18	34.26	65.74	p= .01
t-test sig.	,01			

type 4 – ITPM (fake core white, normal corridor grey)



fake core	#participants	turn to stay	turn to leave
control	19	43	50
experiment	16	56	35
t-test sig.		p= .30	p= .19



fake core	#participants	turn	straight
control	16	33	39
experiment	14	81	11
t-test sig.		P< .005	p= .02

type 4 – ITPM – analyses across all type 4 intersections, grouped by type of action

fake core	#participants	stay	leave
control	19	39,29	45,84
experiment	16	63,03	26,95
t-test sig.		p= .01	p= .05

The evaluation of the type 0 intersections (table 3, section 1) suggests that the fake integration core has at least an indirect influence on decision-making. When participants are already travelling through the Integration core they behave, more or less, in a similar manner to the standard behaviour and we detect no group differences. But when they enter from a non-core corridor the participants are strongly attracted by the fake integration core. Contrary to our original expectations, this behaviour is found in both groups. This indicates that there are other influences in this area than just the local intersection qualities. In this special case the geometric layout of the building might be the cause: When entering the junction from those areas the participants can see that the regular corridor continues a short distance and ends ether in a curve or a t-shaped junction while the other fake core segments – independent of their lighting condition - show longer corridors.

The next junction of interest is type 1 (table 3, section 2) where the fake integration and real integration cores intersect. Here we expect both the fake and real integration core to influence the participants. Therefore we must also look at the two possible points of arrival. When arriving via the fake integration core the control group clearly shows a significant tendency to enter the real integration core, compared to the standard behaviour (t=2.64; df=12; p=.02). For the experiment group this comparison is not significant as here the attraction of the integration core is partly compensated for by the visual properties of the fake core. Unfortunately this difference cannot be further confirmed in the direct group comparison (t= 0.75; df=25.97; p=.47) in this case (again large individual differences in the movement decisions make it difficult to pinpoint the layout effects). Considering the case of arriving from the syntactic integration core, we obtain a clearer pattern of results. The control group behaves almost identical to the standard behaviour while the experiment group shows a different, highly significant behaviour (t=3.01; df=17; p=.01). They are more willing to leave the real integration core for the larger and brighter fake integration core. By looking at the ratios for each of the actions we can see that the values are almost inverse between the control and experiment groups, reflected in a significant statistical difference between the groups (t=2.59; df=33.64; p=.01). Altogether these intersections show that there is an influence on the participants that is connected to their immediate surrounding. This influence is stronger when the participants arrive from the less attractive path and the more interesting - for the control group this is the real and for the experiment the fake integration core - crosses their current path. In those scenarios the participants show a significantly different behaviour from their default. They decided to alter their way and to turn into the respective core that attracted their interest.

The last type to be discussed is the type 4 junction which has a slightly adjusted evaluation and ITMP due to its t-shaped junction. At these intersections the area of arrival is even more relevant because there are several variants. Furthermore there is a possibility that participants walk back the way they came so the percentage of the action doesn't sum up to a 100%. In type 4 intersections the participants always have to take a turn to continue on the fake integration core. The first part of the ITPM show the case where the participant can only choose between a fake integration core and a regular way but need to take a turn either way (Table 3, section 3). Although the percentage values show a difference between groups in the expected direction, and therefore an influence of the fake integration core this pattern fails to reach significance. The second part is even more interesting as they immediately leave the fake integration core, juxtaposing a forward inertia (Conroy Dalton, 2003) with the attractiveness of the visual highlighting. In this case the groups show a significant difference in their behaviour (turn: t=4.88; df=27.56; p=001, straight: t=2.52; df= 28.00;-++-6 p=.02). The final section of table 3 presents a further abstracted evaluation for this intersection type: Here we only looked at the corridor type they choose rather than the action they perform, i.e., whether the participants choose to stay on the fake integration core or to leave. The group comparison is significant both for staying (more prominent in the experimental group; $t=2.65$; $df= 32.80$, $p=.01$) and for leaving (less likely in the experimental group; leave: $t=2.03$; $df=32.08$, $p=.05$) which corresponds to our hypothesis.

Questionnaire

The questionnaire consisted of items with a 1-to-7 scale (1 = strongly disagree; 7 = strongly agree) and was administered at the end of the experiment. One item revealed that the experimental group had a more positive impression of the structure of the building. The question “The building had a clear partition of main corridors and secondary corridors” received an average rating of 2.40 by the control group vs. 3.44 by the experimental group (higher agreement; $t = -2.07$, $df= 28.10$, $p=.05$, marginally significant). From a syntactic point of view one could expect the highlighted fake integration core to distract from the real integration core of the building and might thus obfuscate the structure of the general layout. Nonetheless, the group with the fake integration did perceive a clearer structure. This is in line with the observation that people in the experimental group performed better in the search tasks. It appears that the fake core’s ability to serve as a landmark outweighs this disturbance of overall layout intelligibility.

Both groups gave very low ratings for the question “I could easily orient myself in the building” (experiment group with a 1.94, the control group with a 2.00). Similarly, the question for “When searching the three known landmarks I directly knew how to get there.” received average ratings of 2.06 by the experimental and 2.15 by the control group. The lack of a significant group difference here together with the low agreement scores indicates a statistical floor effect on the two last questions. This observation further supports the notion with respect to the landmark search tasks that the building layout was too complicated for both groups.

4. Discussion, Conclusions & Future work

At the start of the exploration phase, the fake integration core attracted the attention of nearly all the participants of the experimental condition. The time spent exploring the building for the first time is clearly biased towards the fake integration core so that we can conclude that the lighting and corresponding visual factors had strong influence in that phase. This is less clear in the search task phase. Several factors contribute to this observation. High inter-individual variance in wayfinding success may have overshadowed the impact of the main variation. Also, once the participants spent about twenty minutes in the building, they had ample opportunity to realize that the highlighted corridor has no further function and is arbitrarily positioned. The fact that the participants in the experimental condition performed better in the search tasks suggests that it was then used as a landmark and to disambiguate the building. An interesting variation of the present study would be to test what happens if the syntactical core is visually highlighted. It could be highlighted while the fake core is dimmed (yielding another control condition), or in addition to the fake core to examine the behaviour between those two corridors in particular.

With this experiment we aimed to clarify to what extent simple features of a building like colour and brightness of the corridors may have an impact on the navigation in the building and whether such an influence is able to supress syntactic effects in the layout. This is clearly established for the exploration phase, as discussed above. To get a deeper understanding we used the turn matrix of each intersection, which again shows that the participants are clearly attracted by the fake integration core: In the experiment condition the participant where moving into the fake core significantly more often than in the control condition. Upon arriving at an intersection and seeing that their way is crossing the fake integration core the participants are more willing to change their direction and follow this brighter fake integration core than to continue straight along the darker corridor. Once already inside the fake core, if on arrival at a junction intersecting with a non-fake core corridor and the participant must make a turn to stay on the fake-core corridor, then the tendency to prefer the fake-core corridor is reduced. One tentative explanation for this latter finding is that participants use the bright core as a landmark and safe base that they are willing to stray from for further exploration if it fits the task. Future experiments with variations specifically targeting this function will be needed to further clarify this aspect.

The analysis of ITPMs indicates that the intermediate surrounding is clearly influencing the participants in their decisions, both with respect to the syntactic core but especially for the fake integration core. It has become clear in this analysis that for future research on local decision-making the environment should be further refined. Reducing the number of different types of intersections and having more intersections of each type, evenly distributed across the overall environment, would make for cleaner results at the detailed, local level. Nonetheless the results demonstrate that our primary hypothesis is confirmed and this can be observed in different areas of our building. Furthermore the ITPM design provides a format to put as much information as needed in a compact and understandable manner to enable a thorough analysis of the behaviour at the different junctions (with descriptive and inferential statistics included).

This Virtual Reality study has shown the feasibility of the main hypothesis of both structural and perceptual/semantic features having an impact on movement behaviour in wayfinding tasks of exploration and search. While it is an encouraging starting point for this line of research, future studies need to address the inherent limitations of the present design. One aspect is the potentially limited generalizability from highly controlled to realistically diverse real-world buildings, the other is the fact that the high overall difficulty in the search tasks may have obscured important nuances in the interaction of structural and semantic building features. Therefore another line of continuing this should feature a more realistic setting, to reinforce the expectation of a working building (for the impact of semantic expectations also see Frankenstein et al, 2010, 2012). We would suggest maintaining the hospital scenario, but using a simpler and thus easier to learn general layout, as the current one was too complex for the search tasks. In order to further tap into cognitive decision strategies we suggest varying the cognitive demands on perception and planning, e.g. via tight time pressure, or by dynamic rerouting decisions (e.g. obstacles in the building or failing lights). The current building has – for the sake of controlled experimental stimuli – used highly uniform textures. These are in conflict with the degree of architectural differentiation (Weisman, 1981) usually found in real-world buildings and should also be carefully reconsidered.

The main variation in the present paper is the introduction of a highlighted ‘fake integration core’. This approach is related to the doctoral thesis of Rodrigo Mora Vega (2009): He presented abstracted layouts of urban street maps to participants and asked them questions such as ‘where are the shops’ or ‘where is the high street’. This was an indirect measure of which street they thought the most integrated. Initially all streets in the stimuli were redrawn to be the same width, etc., but subsequently the maps were gradually altered, such as increasing the width of a minor, segregated street to determine at what stage people would select this street as the high street or shopping street over the true integrator. In this sense Mora Vega has produced similarly ‘fake cores’, albeit in 2D and on printed maps rather than in egocentric perspective.

On a more general level, our study contributes to the question how cognitive factors are captured by space syntax and which cognitive factors go beyond this syntactic perspective (Penn, 2003; Hillier & Iida, 2005). Note that the syntactic differences between the fake and real integration cores in our study are – somewhat simplistically – only based on traditional axial-line analysis. In the current setting this approach does not capture the impact of corridor width and other local saliency features. Measures based on isovists (Benedikt, 1979) and the subsequent development of Visibility Graph Analysis (VGA; Turner et al, 2001) may be better suited to take such features into account, e.g. the varying isovist sizes at intersections involving highlighted (wider), non-highlighted (narrower) and both types of corridors. In fact, Benedikt (1979) explicitly based his idea of isovists on the perception theories of the psychologist J.J. Gibson (Gibson, 1996). In Gibsonian psychology of perception the impact of the local visual features would clearly be interpreted as "affordances" and should be considered by an integrative account of visual and syntactic determinants of human wayfinding decisions. Franz & Wiener (2008; Wiener et al., 2007) have shown that isovist and VGA measures do capture perceptual qualities of convex spaces with respect to tasks such as identifying good overview or hiding spaces. It will be a task for future studies to determine how we can appropriately measure similar aspects for navigational decision-making in both local geometric and global structural terms.

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